

1 WE CLAIM:

2 1. A process for the production of hydrogen, compris-  
3 ing:

4 a) reacting steam with a vaporizable hydrocarbon at a  
5 temperature of from about 200°C to about 700°C and at a  
6 pressure of from about 1 bar to about 200 bar in a reac-  
7 tion zone containing a reforming catalyst to produce a  
8 mixture of primarily hydrogen and carbon dioxide, with a  
9 lesser amount of carbon monoxide;  
10 b) providing heat to said reaction zone by employing  
11 flameless distributed combustion thereby driving said re-  
12 action;  
13 c) conducting said reaction in the vicinity of a hydro-  
14 gen-permeable and hydrogen-selective membrane, whereby  
15 hydrogen formed in said reaction zone permeates through  
16 said selective membrane and is separated from said carbon  
17 dioxide and carbon monoxide.

1 2. The process of claim 1 wherein the vaporizable hydro-  
2 carbon is selected from the group consisting of natural  
3 gas, methane, methanol, ethane, ethanol, propane, butane,  
4 light hydrocarbons having 1-4 carbon atoms in each mole-  
5 cule, light petroleum fractions including naphtha, die-  
6 sel, kerosene, jet fuel or gas oil, and hydrogen, carbon  
7 monoxide and mixtures thereof.

1 3. The process of claim 1 wherein the flameless dis-  
2 tributed combustion used to drive the reaction comprises:  
3 a) preheating either a fuel gas or oxidant or both to  
4 a temperature that exceeds the autoignition tem-  
5 perature of the fuel gas and oxidant when they  
6 are mixed;  
7 b) passing said fuel gas and oxidant into a heating  
8 zone which is in heat transferring contact along a  
9 substantial portion of said reaction zone; and  
10 c) mixing the fuel gas and oxidant in said heating  
11 zone in a manner that autoignition occurs, result-  
12 ing in combustion without high temperature flames,  
13 thereby providing uniform or tailored, controlled  
14 heat over a substantial portion of said heating  
15 zone which is in contact with said reaction zone.

1 4. The process of claim 3 wherein the fuel gas is  
2 passed through a plurality of tubes in said heating zone,  
3 said tubes having openings sized and spaced to control  
4 the quantity of fuel gas mixed with oxidant at various  
5 points along the heating zone.

1 5. The process of claim 4 wherein the oxidant is air,  
2 and the air and fuel gas used for flameless distributed  
3 combustion are heated to a temperature between about  
4 1000°F and about 2300°F.

1 6. The process of claim 6 wherein the fuel gas is mixed  
2 with oxidant in increments so that upon autoignition the

3 temperature of the resulting combustion gas will rise no  
4 more than from about 20°F to about 200°F.

1 7. The process of claim 4 wherein said heating zone  
2 substantially surrounds said reaction zone.

1 8. The process of claim 7 wherein the plurality of  
2 tubes in the heating zone are placed in a circular pat-  
3 tern in said heating zone.

1 9. The process of claim 2 wherein a sweep gas is used  
2 to promote the diffusion of hydrogen through said mem-  
3 brane.

1 10. The process of claim 9 wherein the sweep gas is se-  
2 lected from the group consisting of steam, carbon diox-  
3 ide, nitrogen and condensable hydrocarbons.

1 11. The process of claim 2 wherein said hydrogen perme-  
2 able membrane comprises one or more Group VIII metals on  
3 a porous ceramic or porous metal support.

1 12. The process of claim 2 wherein the vaporizable hy-  
2 drocarbon is methane or methanol.

1 13. The process of claim 2 wherein the vaporizable hy-  
2 drocarbon is naphtha at boiling point range of 350-500 °F,  
3 or diesel, kerosene or jet fuel at boiling point range of  
4 350-500 °F, or gas oil at boiling point range of 450-800  
5 °F.

1 14. The process of claim 1 characterized by the use of a  
2 reduced steam to vaporizable hydrocarbon ratio without

3 substantial coke formation in said reaction zone heated  
4 by said flameless distributed combustion.

1 15. The process of claim 3 wherein the fuel gas which is  
2 mixed with an oxidant and used for flameless distributed  
3 combustion is hydrogen.

1 16. The process of claim 1 wherein said reforming cata-  
2 lyst comprises at least one Group VIII transition metal  
3 on a support.

1 17. The process of claim 1 wherein said membrane has a  
2 permeability in the range of  $8 \times 10^{-4}$  to 80 standard cubic  
3 meters/m<sup>2</sup>/sec/bar<sup>1/2</sup>.

1 18. The process of claim 11 wherein said hydrogen-  
2 permeable membrane comprises Pd or a Pd alloy.

1 19. The process of claim 1 wherein the temperature in  
2 the reaction zone is from about 300°C to about 600°C and  
3 the pressure is from about 10 bar to about 50 bar.

1 20. The process of claim 11 wherein said membrane has a  
2 permeability in the range of  $8 \times 10^{-3}$  to 70 standard cubic  
3 meters/m<sup>2</sup>/sec/bar<sup>1/2</sup>.

1 21. The process of claim 1 wherein a vacuum is used to  
2 promote the diffusion of hydrogen through said membrane.

1 22. The process of claim 9 wherein the sweep gas is  
2 steam.

1 23. The process of claim 16 wherein said reforming cata-  
2 lyst comprises nickel on alumina.

1 24. The process of claim 19 wherein the temperature in  
2 the reaction zone is from about 400°C to about 500°C.

1 25. The process of claim 18 wherein the hydrogen-  
2 permeable membrane comprises Pd or Pd alloy on a porous  
3 stainless steel support.

1 26. The process of claim 15 wherein the oxidant is air  
2 and the hydrogen and air are combusted at a stoichiomet-  
3 ric ratio of hydrogen to oxygen of 2:1, resulting in a  
4 flue gas stream that has a high concentration of nitrogen  
5 on a dry basis.

1 27. The process of claim 1 characterized in that nitro-  
2 gen oxide formation in the reaction zone heated by said  
3 flameless distributed combustion is at a level below 10  
4 ppm.

1 28. The process of claim 1 wherein the vaporizable hy-  
2 drocarbon and steam provides a minimum overall O:C ratio  
3 of 2:1.

1 29. The process of claim 1 wherein the amount of CO in  
2 the hydrogen which permeates through then membrane is  
3 less than about 10 ppm.

1 30. The process of claim 29 wherein the nitrogen oxide  
2 formation in the reaction zone heated by flameless dis-  
3 tributed combustion is less than 1 ppm.

1 31. The process of claim 25 wherein the Pd alloy is se-  
2 lected from the group consisting of an alloy of Pd with  
3 30-50%w copper, an alloy of Pd with 5-30%w silver, an al-

4   loy of Pd with 1-10%w yttrium, an alloy of Pd with 1-10%w  
5   holmium, an alloy of Pd with 10%w gold, an alloy of Pd  
6   with 1-10%w ruthenium and an alloy of Pd with 1-10%w ce-  
7   rium.

1   32. The process of claim 1 wherein the hydrogen perme-  
2   able membrane has a thickness in the range of 0.1 to 20  
3   μm.

1   33. The process of claim 32 wherein the hydrogen perme-  
2   able membrane has a thickness of 0.5 to 3μm.

1   34. A process for the production of high purity hydrogen  
2   and the use thereof in generating electricity which com-  
3   prises:

- 4       a) reacting steam with a vaporizable hydrocarbon at a  
5       temperature of about 200°C to about 700°C and a  
6       pressure of from about 1 to about 200 bar in a re-  
7       action zone containing reforming catalyst to pro-  
8       duce a mixture of primarily hydrogen and carbon  
9       dioxide, with a lesser amount of carbon monoxide;
- 10      b) providing heat to said reaction zone by employing  
11      flameless distributed combustion thereby driving  
12      said reaction;
- 13      c) conducting said reaction in the vicinity of a hy-  
14      drogen-permeable and hydrogen selective membrane,  
15      whereby hydrogen formed in said reaction zone per-  
16      meates through said selective membrane and is

17 separated from said carbon dioxide and carbon mon-  
18 oxide; and  
19 d) directing said separated hydrogen to the anode of  
20 a fuel cell.

1 35. The process of claim 34 wherein the fuel cell is a  
2 high pressure molten carbonate fuel cell and the non per-  
3 meable by-product gases from the reaction zone are di-  
4 rected to the cathode of said fuel cell.

1 36. The process of claim 35, which further comprises the  
2 separation and sequestration of high concentrations of  
3 carbon dioxide from the process streams and/or from other  
4 external CO<sub>2</sub>-containing streams.

1 37. The process of claim 35 wherein nitrogen is obtained  
2 as a high purity stream from the outlet of the cathode of  
3 a molten carbonate fuel cell.

1 38. The process of claim 35 wherein the efficiency in  
2 the generation of electricity from the vaporizable hydro-  
3 carbon starting fuel is 71% or greater.

1 39. The process of claim 34 wherein the fuel cell is a  
2 PEM fuel cell or a solid oxide fuel cell.

1 40. A steam reforming process for producing high purity  
2 hydrogen and CO<sub>2</sub> which comprises:

3 a) providing a generally tubular reforming chamber  
4 having one or more inlets for a vaporizable, hy-  
5 drocarbon and steam and one or more corresponding  
6 outlets for byproduct gases, including H<sub>2</sub>O, and

7 CO<sub>2</sub>, with a flow path in between said inlet and  
8 outlet, and  
9 one or more inlets for sweep gas and correspond-  
10 ing outlets for sweep gas and hydrogen, with a  
11 flow path between said inlet and outlet, and  
12 one or more inlets for preheated oxidant and cor-  
13 responding inlets for fuel gas mixtures, with a  
14 flow path between said inlets containing a plural-  
15 ity of flameless distributed combustion heaters,  
16 Wherein said flow path for vaporizable hydrocarbon  
17 and flow path for sweep gas forms two concentric  
18 sections with an annulus between having a reform-  
19 ing catalyst therein and including a permeable  
20 membrane on the inside or outside of the concen-  
21 tric sections;

22 b) Feeding into said reforming chamber through said  
23 one or more inlets a stream of vaporizable hydro-  
24 carbon and steam;

25 c) Flowing said vaporizable hydrocarbon over a re-  
26 forming catalyst;

27 d) Causing steam reforming to take place in said re-  
28 forming chamber; and

29 e) Conducting said reforming in the vicinity of a hy-  
30 drogen permeable and hydrogen-selective membrane,  
31 whereby pure hydrogen permeates said membrane;



32 f) Wherein heat to drive said reaction is provided by  
33 said flameless distributed combustors.

1 41. The process of claim 40 wherein the temperature in  
2 said reforming chamber is from about 200°C to about  
3 700°C.

1 42. The process of claim 41 wherein the vaporizable hy-  
2 drocarbon is selected from the group consisting of natu-  
3 ral gas, methane, methanol, ethane, ethanol, propane, bu-  
4 tane, light hydrocarbons having 1-4 carbon atoms in each  
5 molecule, light petroleum fractions including naphtha at  
6 boiling point range of 350-500 °F, or diesel, kerosene or  
7 jet fuel at boiling point range of 350-500 °F, or gas oil  
8 at boiling point range of 450-800 °F, hydrogen, carbon  
9 monoxide and mixtures thereof.

1 43. The process of claim 42 wherein the sweep gas is se-  
2 lected from the group consisting of steam, carbon diox-  
3 ide, nitrogen and condensable hydrocarbons.

1 44. The process of claim 40 wherein the flameless dis-  
2 tributed combustion used to heat the reforming chamber  
3 comprises:

4 a) preheating either a fuel gas or oxidant or both  
5 to a temperature that exceeds the autoignition tem-  
6 perature of the fuel gas and oxidant when they are  
7 mixed;

8 b) passing said fuel gas and oxidant into said  
9 heating section which is in heat transferring con-

10 tact along a substantial portion of said reforming  
11 chamber; and  
12 c) mixing the fuel gas and oxidant in said heating  
13 section in a manner that autoignition occurs, re-  
14 sulting in combustion without high temperature  
15 flames, thereby providing uniform, controllable heat  
16 over a substantial portion of said heating zone  
17 which is in contact with said reforming chamber.

1 45. The process of claim 40 wherein said plurality of  
2 flameless distributed combustion heaters are placed in a  
3 circular pattern in the outer concentric section.

1 46. The process of claim 41 wherein said inlet stream of  
2 vaporizable hydrocarbon and steam pass into said reform-  
3 ing chamber and into contact with said catalyst and one  
4 side of said hydrogen-selective membrane to produce CO<sub>2</sub>,  
5 CO and H<sub>2</sub>.

1 47. The process of claim 44 further comprising passing a  
2 separate stream including steam, carbon dioxide, nitro-  
3 gen, or condensable hydrocarbon through an inlet adjacent  
4 to the opposite side of said membrane in such manner as  
5 to promote hydrogen diffusion through said membrane from  
6 one side to the opposite side thereof, thereby causing  
7 more complete conversion of said originally supplied hy-  
8 drocarbon.

1 48. The process of claim 47 wherein said sweep gas is  
2 passed counter current to the path of the vaporizable hy-  
3 drocarbon.

1 49. The process of claim 45 further comprising removing  
2 hydrogen from the opposite side of said membrane.

1 50. The process of claim 40 wherein said hydrogen that  
2 permeates said permeable membrane is recovered by a vac-  
3 uum means, wherein when a vacuum is used to recover hy-  
4 drogen, the inlet on the permeate side is not used be-  
5 cause no sweep gas is required, and only the outlet is  
6 required.

1 51. The process of claim 44 wherein said vaporizable hy-  
2 drocarbon is selected from the group consisting of natu-  
3 ral gas, methane, methanol, ethane, ethanol, propane, bu-  
4 tane, light hydrocarbon having 1-4 carbon atoms in each  
5 molecule, light petroleum fractions, including naphtha at  
6 boiling point range of 120-400 °F, or diesel, kerosene or  
7 jet fuel at boiling point range of 350-500 °F, or gas oil  
8 at boiling point range of 450-800 °F, hydrogen, carbon  
9 monoxide and mixtures thereof.

1 52. The process of claim 44 wherein said vaporizable hy-  
2 drocarbon consists essentially of methane.

1 53. The process of claim 40 wherein said stream of va-  
2 porizable hydrocarbon includes carbon and steam at a  
3 minimum overall O:C ratio of 2:1.

1 54. The process of claim 40 wherein said reforming cham-  
2 ber is at a temperature in the range of from about 300 to  
3 about 650°C.

1 55. The process of claim 54 wherein said reforming cham-  
2 ber is at a temperature in the range of from about 400 to  
3 about 550 °C.

1 56. The process of claim 55 wherein the temperature  
2 range permits the use of less expensive materials in con-  
3 struction.

1 57. The process of claim 56 wherein said reforming cham-  
2 ber is constructed of less expensive materials, contain-  
3 ing less chromium and nickel, not suitable for similar  
4 steam methane reformers in the art which must operate at  
5 higher temperatures.

1 58. The process of claim 55 wherein said reforming  
2 chamber is constructed of an alloy containing less than  
3 25% Cr and less than 20% Ni, with most of the balance  
4 comprising iron.

1 59. The process of claim 55 wherein the reforming cham-  
2 ber is constructed of AISI 304 stainless steel, compris-  
3 ing about 18% Cr, about 8% Ni, and the balance Fe or AISI  
4 316 L stainless steel.

1 60. The process of claim 40 wherein said reforming cham-  
2 ber is at a pressure at a minimum of one bar absolute.

1 62. The process of claim 41 wherein said reforming  
2 chamber is at a pressure in the range of 1 to 200  
3 Bar.

1 62. The process of claim 42 wherein the reforming cham-  
2 ber is at a pressure in the range of 10-100 Bar.

1 63. The process of claim 40 wherein said reforming cata-  
2 lyst comprises at least one Group VIII transition metal.

1 64. The process of claim 63 wherein said reforming cata-  
2 lyst comprises nickel.

1 65. The process of claim 64 wherein said reforming cata-  
2 lyst is on a support.

1 66. The process of claim 65 wherein said support is se-  
2 lected from the group consisting of oxides, carbides, or  
3 nitrides of Group III A , IIIB, IV A, IVB, or Group VIII  
4 metals of the Periodic Table.

1 67. The process of claim 66 wherein said support is se-  
2 lected from the group consisting of porous metal oxides  
3 that are inert on their own and porous metal oxides that  
4 have the capacity to passivate the surface of a support.

1 68. The process of claim 67 wherein the support is a po-  
2 rous metal oxide.

1 69. The process of claim 68 wherein the support com-  
2 prises alumina.

1 70. The process of claim 69 wherein said reforming cata-  
2 lyst comprises nickel on alumina.

1 71. The process of claim 40 wherein said hydrogen-  
2 permeable membrane comprises one or more Group VIII tran-  
3 sition metals or alloys thereof.

1 72. The process of claim 40 wherein said vaporizable hy-  
2 drocarbon is syngas.

1 73. The process of claim 72 wherein said hydrogen perme-  
2 able-membrane is situated on a porous ceramic or porous  
3 metallic support.

1 74. The process of claim 73 wherein the support com-  
2 prises a porous metal.

1 75. The process of claim 73 wherein the support com-  
2 prises a porous ceramic.

1 76. The process of claim 75 wherein the support com-  
2 prises alumina.

1 77. The process of claim 74 wherein the support com-  
2 prises porous stainless steel or Inconel or Hastelloy.

1 78. The process of claim 77 further comprising an inter-  
2 mediate layer between said support and said membrane.

1 79. The process of claim 75 further comprising the sup-  
2 port serves as a thermal insulating layer to assist in  
3 keeping the membrane at a desired temperature.

1 80. The process of claim 76 further comprising the con-  
2 centration of alumina permits the tailoring of the design  
3 to emphasize insulating or conducting properties.

1 81. The process of claim 71 wherein said hydrogen-  
2 permeable membrane is selected from palladium and palla-  
3 dium alloys.

1 82. The process of claim 81 wherein said hydrogen-  
2 permeable membrane comprises at least one of an alloy of  
3 Pd with 30-50 wt% copper, an alloy of Pd with 5-30 wt%  
4 silver, an alloy of Pd with 1-10 wt% yttrium, an alloy of  
5 Pd with 1-10 wt% holmium, an alloy of Pd with 1-10 wt%  
6 gold, an alloy of Pd with 1-10 wt% ruthenium, and an al-  
7 loy of Pd with 1-10 wt% cerium.

1 83. The process of claim 71 wherein said hydrogen-  
2 permeable membrane is selected from platinum and platinum  
3 alloys.

1 84. The process of claim 72 wherein said membrane has a  
2 thickness in the range of 10 Angstroms to 150 $\mu$ m.

1 85. The process of claim 72 wherein said membrane has a  
2 thickness in the range of 0.1 to 20 $\mu$ m.

1 86. The process of claim 81 wherein said membrane has a  
2 thickness in the range of 0.5 to 3  $\mu$ m.

1 87. The process of claim 40 wherein said membrane has a  
2 permeability in the range of  $8 \times 10^{-4}$  to 80 standard cubic  
3 meters/ $\text{m}^2/\text{sec}/\text{bar}^{1/4}$ .

1 88. The process of claim 87 wherein said membrane has a  
2 permeability in the range of  $8 \times 10^{-3}$  to 70 standard cubic  
3 meters/ $\text{m}^2/\text{sec}/\text{bar}^{1/4}$ .

1 89. The process of claim 40 wherein the use of said mem-  
2 brane permits fewer unit operations in the process.

1 90. The process of claim 40 characterized in that nitro-  
2 gen oxide formation is reduced to a level below 10 ppm.

1 91. The process of claim 90 wherein nitrogen oxide for-  
2 mation is reduced to a level below 1.0 ppm.

1 92. The process of claim 91 wherein nitrogen oxide for-  
2 mation is reduced to a level below 0.1 ppm.

1 93. The process of claim 40 wherein said flameless dis-  
2 tributed combustion comprises:

3 a) passing an oxidant through said inlet to a mixing  
4 point;

5 b) passing fuel gas through said corresponding inlet  
6 to a mixing point within the pathway between the  
7 two inlets juxtapose to the point to be heated;

8 c) preheating either the fuel gas or oxidant or both  
9 such that the temperature of the mixed stream ex-  
10 ceeds an autoignition temperature of the mixture of  
11 the streams; and

12 d) combining the preheated oxidant and fuel gas at the  
13 mixing point resulting in autoignition forming com-  
14 bustion products.

1 94. The process of claim 93 wherein said flameless dis-  
2 tributed combustors further comprise:



3 a) an axial combustion chamber in communication with an  
4 inlet for oxidant at one end and in communication with  
5 a combustion product outlet at the other end;  
6 b) a fuel conduit within the axial combustion chamber,  
7 the fuel conduit defining a fuel volume, the fuel vol-  
8 ume in communication with the fuel supply, and in com-  
9 munication with the combustion chamber through a plu-  
10 rality of orifices along the fuel conduit wherein the  
11 fuel conduit comprises an electrically conductive ma-  
12 terial; and  
13 c) any method of preheating air effective to heat the  
14 fuel conduit in the vicinity of at least one orifice  
15 to temperature above a temperature at which the fuel  
16 will ignite when the fuel passes through the orifices.

1 95. The process of claim 40 further comprising said sec-  
2 tion containing said membrane is packed with a methana-  
3 tion catalyst to react with any trace amounts of CO that  
4 escape through said membrane.

1 96. The process of claim 95 wherein said methanation  
2 catalyst is nickel or iron or copper based.

1 97. The process of claim 40 further comprising said  
2 steam reformer can function alone as a hydrogen generator  
3 to supply a source of hydrogen for any process requiring  
4 a source of hydrogen.

1 98. The process of claim 97 wherein said steam reformer  
2 can function alone as a hydrogen generator to supply a

3 source of hydrogen for any process selected from the  
4 group consisting of production of ammonia, production of  
5 electricity, refining, semiconductor processing, hydrogen  
6 peroxide manufacture, hydrogenation of chemical interme-  
7 diates and production of hydrogen for chemical analytical  
8 testing.

1 99. A process for the production of pure hydrogen and  
2 the use thereof in a zero emission hybrid power system  
3 which comprises:

4 a) Providing a generally tubular reforming chamber hav-  
5 ing one or more inlets for a vaporizable hydrocarbon  
6 and steam and one or more corresponding outlets for by-  
7 product gases, including  $H_2O$  and  $CO_2$ , with a flow path  
8 in between said inlet and outlet,  
9 and one or more inlets for and corresponding outlets  
10 for sweep gas and hydrogen, with a flow path between  
11 said inlet and outlet, and  
12 an inlet for preheated air and a corresponding inlet  
13 for fuel gas mixtures, with a flow path between said  
14 inlets containing a plurality of flameless distributed  
15 combustion heaters,  
16 wherein said flow path for vaporizable hydrocarbon and  
17 flow path for sweep gas form two concentric sections  
18 with an annulus between having a reforming catalyst  
19 therein and a hydrogen permeable membrane on the inside  
20 or outside of one of the concentric sections;

21 b) Feeding into said reforming chamber through said  
22 inlets a vaporizable hydrocarbon and steam;  
23 c) Flowing said vaporizable hydrocarbon over said re-  
24 forming catalyst;  
25 d) Causing steam reforming to take place in said re-  
26 forming chamber;  
27 e) Conducting said reforming in the vicinity of a hy-  
28 drogen permeable and hydrogen-selective membrane,  
29 whereby pure hydrogen permeates said membrane;  
30 f) directing said pure hydrogen to the anode of a fuel  
31 cell and directing by-product gases to the cathode  
32 of said fuel cell;  
33 g) Wherein heat to drive the reaction in said reforming  
34 chamber is provided by said flameless distributed  
35 combustion.

1 100. The process of claim 99 wherein steam, carbon diox-  
2 ide, nitrogen, or a condensable hydrocarbon is used as a  
3 carrier of hydrogen.

1 101. The process of claim 100 wherein the fuel cell is a  
2 high-pressure fuel cell.

1 102. The process of claim 101 wherein the fuel cell is a  
2 high-pressure molten carbonate fuel cell.

1 103. The process of claim 102, which further comprises  
2 the separation and sequestration of high concentrations  
3 of carbon dioxide from the process streams and/or from  
4 other external CO<sub>2</sub>-containing streams.

1 104. The process of claim 103 wherein said carbon dioxide  
2 is used to make chemicals.

1 105. The process of claim 99 wherein the carbon dioxide  
2 stream, the hydrogen stream or the nitrogen stream from  
3 the process is used to make urea, ammonia or ammonium  
4 sulfate.

1 106. The process of claim 40 wherein said carbon dioxide  
2 is used in oil recovery.

1 107. The process of claim 103 wherein said carbon dioxide  
2 is used in oil recovery.

1 108. The process of claim 40 wherein the carbon dioxide  
2 is used in coal beds.

1 109. The process of claim 103 wherein said carbon dioxide  
2 is used in coal beds.

1 110. The process of claim 40 wherein the carbon dioxide  
2 is used in secondary or tertiary oil recovery.

1 111. The process of claim 103 wherein the carbon dioxide  
2 is used in secondary or tertiary oil recovery.

1 112. The process of claim 99 which produces essentially  
2 negligible amounts of NO<sub>x</sub>.

1 113. The process of claim 112 wherein the NO<sub>x</sub> formation is  
2 reduced to a level below 10 ppm.

1 114. The process of claim 113 wherein the NO<sub>x</sub> formation  
2 is reduced to a level below 1.0 ppm.

1 115. The process of claim 114 wherein the NO<sub>x</sub> formation is  
2 reduced to a level below 0.1 ppm.

1 116. The process of claim 102 wherein the presence of  
2 negligible amounts of NO<sub>x</sub> greatly enhances performance and  
3 efficiency of said method.

1 117. The process of claim 99 further characterized by a  
2 material and energy efficiency advantage comprising a  
3 tight material and energy integration between the Mem-  
4 brane Steam Reforming reactor (MSR) and the Molten Car-  
5 bonate Fuel Cell (MCFC) characterized by:

6 a) Feeding carbon dioxide made in the FDC heater and  
7 the membrane steam reformer to the molten carbonate  
8 fuel cell;

9 b) Recycling the water used as membrane steam reformer  
10 sweep gas plus water made in the molten carbonate  
11 fuel cell, back to the membrane steam reformer  
12 feed, thus, reducing water emissions to a minimum  
13 purge stream, and obviating the need of a fresh wa-  
14 ter supply;

15 c) Using the pressure and temperature of specific out-  
16 let streams to generate electricity in turbines, in-  
17 stead of resulting in waste heat; and

18 d) Using the enthalpy of specific outlet streams to ex-  
19 change heat with given inlet streams for reduction  
20 in net fuel usage.

1 118. The process of claim 40 further characterized by ad-  
2 vantages in terms of distributed production of hydrogen  
3 on demand without storage requirements.

1 119. The process of claim 99 further comprising the op-  
2 tion of using a vaporizable hydrocarbon produced in a re-  
3 mote location to produce electricity for transportation  
4 to nearby residential or commercial markets instead of  
5 transporting by pipeline.

1 120. The process of claim 119 wherein the vaporizable hy-  
2 drocarbon is natural gas.

1 121. The process of claim 40 wherein the high purity hy-  
2 drogen stream produced is used in a PEM fuel cell to gen-  
3 erate electricity.

1 122. The process of claim 40 wherein the fuel fed to the  
2 FDC heaters is hydrogen.

1 123. The process of claim 122 wherein the fuel fed to  
2 the FDC heaters is hydrogen and it is combusted with air,  
3 at the stoichiometric ratio to oxygen of 2:1, resulting  
4 in a flue gas stream that is pure in nitrogen on dry ba-  
5 sis.

1 124. The process of claim 99 wherein nitrogen is obtained  
2 as a high purity steam from the outlet of the cathode of  
3 the molten carbonate fuel cell.

1 125. The process of claim 124 wherein nitrogen is used  
2 for any process requiring a source of nitrogen.

1 126. The process of claim 124 wherein nitrogen is used  
2 for any process selected from the group consisting of  
3 production of ammonia, nitric acid, urea and ammonium  
4 sulfate.

1 127. The process of claim 40 wherein carbon dioxide is  
2 used for any process selected from the group consisting  
3 of production of urea or building materials or food prod-  
4 ucts or carbonated drinks.

1 128. The process of claim 41 wherein the FDC section does  
2 not have a fuel inlet, but rather uses the permeated hy-  
3 drogen is used as a fuel in the FDC heating section with  
4 air or oxygen as the oxidant.

1 129. The process of claim 1 wherein between 90 and 95% of  
2 the heat generated by flameless distributed combus-  
3 tion in the heating zone is transferred to the re-  
4 acting fluids in said reaction zone.

5 130. The process of claim 1 wherein the vaporizable hy-  
6 drocarbon comprises partly or entirely of a syngas  
7 stream from a Catalytic Partial Oxidation process.